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CHEMICAL BIRD REPELLENTS: APPLICABILITY FOR DETERRING USE OF WASTE WATER

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Abstract: Regulatory agencies have placed increasing emphasis on agriculture and industry to protect wildlife from mortality associated with the consumption of waste water. Traditional hazing methods to keep birds away from areas have met with marginal success. The only effective commercially available solution is to enclose impoundments with netting. This strategy is costly and is subject to engineering constraints when large areas are to be protected. Molecular modeling techniques were used to identify chemical repellents to be added to waste water. These repellents effectively prevent birds from drinking or swimming in treated water. The most effective repellents are those containing an electron donating amino group ortho to a neutral or electron withdrawing group (EWG) on a phenyl ring, and where the electron donating group is largely in the same pi orbital as the EWG. Factors that tend to hinder electron donation to the phenyl ring, i.e., electronic or stearic effects, tend to diminish repellency of a chemical.

Elimination of an attractive nuisance decreases the likelihood that migratory birds will stay at mine sites for long, thereby decreasing the probability of kills. The techniques described here allow us to screen for repellency from a host of prospective compounds and select those best suited to the application, development and cost constraints of specific industries, e.g., protection of formulated turf and crop pesticides, livestock food additives to reduce feed loss to birds, additives to reduce water use (airports, mine sites). Reliance on nonlethal repellents for bird control poses several advantages, the most important being a sound environmental strategy for conflict resolution between wildlife and agriculture/industry interests.

Growing human populations place increasing demands on agriculture and industry. Processes from industry/agriculture often produce by-products, such as waste water, which must be stored in impoundments until they can be safely processed. While these impoundments may meet Federal and State regulations pertaining to protection of groundwater, they often pose an inherent risk to wildlife (Allen 1990, Kay 1990). Waterfowl and other species are often attracted to freestanding water. Should the wildlife drink from impoundments they risk death or the bioaccumulation of toxic substances, e.g. heavy metals and mutagens. There is ample evidence to indicate that bioaccumulation of toxicants can decrease the reproductive capacity of waterfowl, and hence negatively affect wildlife populations (Ohlendorf et al. 1989, Williams et al. 1989). In other cases, the actual impact of impoundments on wildlife populations may be negligible, but because of treaty concerns, protection of wildlife is an important issue, e.g., The Migratory Bird Treaty Act (16 USC 703-711) sets zero tolerance for bird mortality. Traditional hazing methods are often ineffective at achieving zero mortality (Jackson 1990). The only current commercially available effective means of preventing wildlife from using ponds is exclusion by netting. Because waste water ponds typically range from 1 to 400 acres this option is often impractical for logistic and economic reasons.

U.S. sales derived from the gold/silver mining industries were over $3.3 billion for 1989. Because cyanide is used for the extraction of these metals from ore, the leachate impoundments are highly toxic to wildlife. Eliminating cyanide from ponds via quenching is an expensive proposition running about $240,000–400,000/year for a mid-sized operation. Excluding birds from ponds until cyanide reclamation or quenching can be achieved is also costly, running between $9,000–13,000/acre, resulting in a range of $36,000–404,000 for a range of pond sizes from 3 to 45 acres (Schroeder 1990). One company, FMC Gold Company, spent $8 million at the Paradise Peak Mine to exclude waterfowl; this investment resulted in reducing avian mortality from 1,548 in 1986-87 to 88 in 1988-89 (Allen 1990, Department of Wildlife, *State of Nevada statistics on bird mortality*). The inability to reduce mortality to zero reflects the failure of netting under variable and severe weather conditions. Despite substantial reductions in avian mortality, the results of attempted exclosure still do not meet the requirements set forth by statutes. Clearly an economical alternative or ancillary strategy for keeping birds out of toxic free-standing water is needed.

Avoidance of a compound can be based upon post-ingestional factors, e.g., toxicity, where a conditioned aversion to a sensory cue is learned. Avoidance can also be mediated via purely sensory cues. In this case no post-ingestional conditioning occurs, nor is there chemical or physical damage to the organism. For purely sensory repellents, the emerging picture is that there are clear perceptual differences between birds and mammals. For example, mammals find capsaicin (the agent responsible for the hotness in *Capsicum* chili peppers) irritating, whereas birds are indifferent to concentrations as high as 20,000 ppm (Szolcsanyi et al. 1986). Alternatively, methyl or dimethyl anthranilate (grape flavoring) are highly repellent to birds, yet mammals are either indifferent or prefer the compound (Kare 1961, Mason et al. 1985, Glahn et al. 1989). Stimulation of trigeminal fibers is an important component of repellency in vertebrates (Alarie 1990). In birds, olfaction and trigeminal chemoreception underlie the aversiveness of methyl and dimethyl anthranilate, suggesting that avoidance is based upon odor quality and irritation (Mason et al. 1989). This is in sharp contrast to earlier studies, which supported the popular belief that the limited taste capacities of birds mediated repellency (e.g., Kare and Pick 1960, Rogers 1978). Recent studies support the thesis that birds are fully capable of making quantitative and qualitative odor discriminations (Walker et al. 1979, Mason and Silver 1983, Clark and Mason 1987, Mason et al. 1989, Clark and Mason 1989, Clark and Smeraski 1990, Clark and Shah 1991, Clark 1991). Presumably stimulation of the trigeminal nerves provides information on irritancy only, while stimulation of the olfactory receptors provides qualitative sensory cues useful in stimulus identification (Mason and Silver 1983, Silver et al. 1988).

In contrast, compounds that repel both birds and mammals always appear to operate in a post-ingestive mode via conditioned avoidance, e.g., thiram and methiocarb (Johnson et al. 1982). This raises fundamental questions about the nature of receptors and coding for purely sensory irritants between these two taxonomic classes. From an anatomical and histological perspective, the two taxa appear to be similar, though comparative taxonomic information on the structure of the trigeminal system as it pertains to chemical signals is limited. Explanation of this taxonomic difference is of both fundamental and practical interest. For example, irritation may reflect phylogenetic constraints present at the time of divergence for each group or an evolutionary response to selective pressures relating to chemical ecology prevailing at the time of divergence. Practically, the ability to identify ecologically sound avian repellents has numerous advantages, the most important of which are that birds can be kept away from crops, formulated pesticides or rodenticides, or areas where they pose a hazard to themselves and/or humans, e.g., airports, waste water impoundments.

The Environmental Protection Agency currently has 95 compounds registered for bird control. The majority are lethal bird control agents. Even some that are marketed as bird repellents, actually function as avicides, e.g. avitrol™, and thus, are not suitable for nonlethal control. Furthermore, unless careful prebaiting techniques are employed, risk to nontarget species can be high. There are only two EPA registered chemicals that function as nonlethal bird control agents: measurol™ and polybutene products. The former functions as a post-ingestive conditioning agent, while the latter is a contact irritant (e.g., Tanglefoot™).

Several other groups of chemicals are known to be bird repellents, but until recently the discovery of general or taxon-specific repellents was empirical, resulting in a narrow list of potential avian repellents (Kare 1961, Goodhue et al. 1963, Mason et al. 1988). The diversity of applications may impose constraints on the type of repellent that can be used, i.e., interaction with application media or delivery vehicle, registration concerns, efficacy. Thus, the more diverse the potential list, the better the chance for identifying a repellent suitable for a specific application. A more systematic and theoretical approach would be of great utility for practical reasons, i.e., the ability to predict repellency from chemical structure.

A series of studies and observations suggested the research be concentrated on derivatives of a basic phenyl ring structure and formulate a model that accurately predicts bird repellents (Mason et al 1989, 1991b, Clark and Shah 1991, Clark et al. 1991, Shah et al 1991). From this model a bird repellent should have one of the core structures depicted in Figure 1, with R_1, R_1' or R_1'' being electron donating groups (EDG) (R_1 can be in the ortho, meta or para position). R_2 can be an electron withdrawing group (EWG), or a neutral group that does not substantially hinder electron donation to the phenyl ring by the EDG. Other factors can modulate the strength of repellency of the basic core structure. For example, resonance is an important factor contributing to repellency. Compounds with the EDG in the ortho position are more potent repellents than those with the EDG in the para position. Compounds with the EDG in the meta position are normally only weakly repellent, if at all. The capacity to form a heterocyclic ring structure incorporating R_1 and R_2 is also an important feature of good repellents. This necessitates that R_1 be ortho to R_2. Such a structure tends to keep the EWG and EDG in the same pi orbital and reduce the likelihood that electronic or stearic effects will hinder electron donation to the phenyl ring. This may also be accomplished if an intramolecular hydrogen bond is formed between R_1 and R_2. Finally, the more basic the substituent for R_1, the better the likelihood of repellency, e.g., amines contribute to repellency better than methoxyl groups, which in turn are better than hydroxyl groups. Molecules that combine the best of these described features are most often the more potent repellents.

This paper presents initial findings on methods to reduce consumption of toxic free-standing water by birds to zero, or to levels within the toxicological tolerance of avian species. In other words, a method to reduce the risk of mortality to birds. The best repellents were selected from a series of previously conducted tests with the goal of

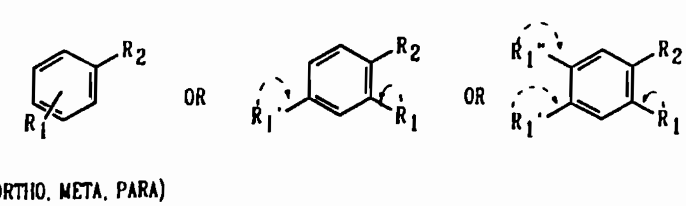

Figure 1. The core structures of some avian repellents. R1, R1', and R1" are electron donating groups. R2 is an electron withdrawing or neutral group. The arrows indicate donation of lone pairs of electrons to the phenyl ring.

determining how efficacy changed once the compounds were placed in a hostile chemical environment, i.e., dump leachate pond water derived from a gold mining operation.

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METHODS

Birds

Adult European starlings (*Sturnus vulgaris*) were captured at the Philadelphia Zoo using funnel traps. Birds were transported from the zoo to the Monell Center via car. Upon arrival at the laboratory, the birds were individually caged (61x36x41 cm) under a 12:12 light:dark cycle. During a two-week adaptation period prior to testing, all birds were given free access to Purina Flight Bird Conditioner (Purina Mills, St. Louis, MO), water and medicated oyster shell grit (United Volunteer Aviaries, Nashville, TN).

Experiment 1: Tolerance of Starlings to NaCN Consumption.

Published data were not available on toxic dosages of sodium cyanide for birds. Anecdotal evidence based upon kill reports at cyanide ponds indicated that cyanide content below 50 ppm does not pose a serious threat to birds. Cyanide concentration of the water source alone, however, will not yield information on the acute dose a bird may receive. One must also know the volume of water consumed over a specified period. This latter factor, in addition to tolerance of the toxicant, may vary considerably among species. Starlings were challenged in a forced choice drinking trial with varying concentrations of sodium cyanide solution to gain a better understanding of the effect of acute consumption of contaminated water. Six concentrations of sodium cyanide solution were prepared: 5000, 1000, 500, 100, 50, and 10 ppm.

A one-choice drinking test was used to evaluate repellency, where birds were presented with richter tubes (graduate water drinking tubes) containing plain water (pre and posttreatment periods) or sodium cyanide solution (treatment day). Birds were monitored for malaise, morbidity and mortality for 48 hours after consumption of the treated water. In the absence of malaise, a decrement of consumption was taken as a measure of sodium cyanide's repellency relative to an individual's pretreatment consumption.

Starlings were given three days of pretreatment during which water consumption was measured for six hours each day. At the end of this period, individuals whose variance about the three-day mean consumption was greater than ± 1 standard deviation of the population variance were excluded from the trials. Those birds with stable daily water consumption were ranked according to mean water consumption and assigned to one of the six treatment (concentration) groups. The bird with the highest water consumption was assigned to the first treatment group (i.e., 5000 ppm), the bird with the second highest consumption (i.e., 1000 ppm) was assigned to the second treatment group, and so forth, until all birds were assigned to a group. This assured that all groups were balanced with respect to drinking when treatment trials began. A total of 36 birds were used for experiments, with 6 birds per treatment group.

After assignment to a treatment group, a one-day pretreatment drinking trial was initiated. Beginning at 0930, the tap water was replaced with deionized distilled water and consumption was recorded every two hours for the next six hours. This allowed us to correct for spillage effects. After the test, birds were again provided free access to tap water. Consumption of tap water was monitored overnight. The treatment period began at 0930 the next day, when birds were given their preassigned concentrations of sodium cyanide solution. Consumption was recorded every two hours for six hours. After the test, birds again were given free access to tap water and consumption was monitored overnight. During the posttreatment period the following day, consumption of deionized distilled water was recorded every two hours for a total of six hours. Overnight consumption was monitored to evaluate whether birds made up for any water deficits resulting from experiments. The within group, six-hour posttreatment water consumption was compared with the mean within group, six-hour pretreatment water consumption to determine whether consumption returned to pretreatment levels.

Data for analyses were transformed using a difference score to control for individuals' pretreatment water consumption, i.e., treatment–pretreatment and post-treatment–pretreatment. Two a priori hypotheses about consumption of treated water were tested. (1) Did the relative mean water consumption differ among the treatment groups? A one-way anova was used to compare group means and a Tukey's B post-hoc test was used to identify significant ($P<0.05$) differences among means. (2) Did the relative consumption of treated water differ from a theoretical value of zero consumption? This hypothesis is of practical interest because there may be times when a bird must be repelled absolutely from potentially lethal toxic waste water, e.g.,

-cyanide ponds resulting from precious metal extraction in the gold mining industry (McQuivey 1990). The analysis required a slight modification in calculation of the treatment sums of squares, where the grand mean was replaced by zero and the degrees of freedom (df) reflected the number of treatments considered in the experiment (i.e., k = 12). Estimates of the error term remained the same as in a standard anova. Post-hoc comparisons were made using a modification of Dunnett's *t*-test (1955), again using a theoretical value of zero rather than the mean, and comparing the resulting *t* to critical values in Dunnett's calculated distribution with P set at < 0.05. Unless otherwise indicated, all data were tested and found to be homogeneous using Bartlett's-Box method.

Experiment 2: Efficacy of Repellents in Dump Leachate Pond Water

In an earlier series of papers, the structure-activity relationships between anthranilates, acetophenones, benzoic acids and veratryl alcohols and their derivatives to repellency in birds were studied (Mason et al. 1989, 1991, Clark and Shah 1991, Clark et al. 1991, Shah et al. 1991). These papers presented the theoretical framework by which bird repellents can be predicted on the basis of chemical structure. In the present study, eight of the best repellents from past studies and two arbitrarily selected weakly repellent chemicals were screened for their ability to deter consumption of pond water containing sodium cyanide. The chemicals included in this study were: o-aminoacetophenone (OAP; CAS#551-93-9), 4-ketobenztriazine (4KBT; CAS # 90-16-4), methyl anthranilate (MA; CAS # 25628-84-6), veratryl amine (VAM, CAS # 5763-61-1), cinnamamide (CIN; CAS # 621-79-4), 2-amino-4,5-dimethoxyacetophenone (2A45DAP; CAS # 4101-30-8), methyl-2-methoxybenzoate (M2MOB; CAS # 606-45-1), N-acetylveratrylamine (NVAM; this compound was synthesized in the laboratory), 2-methoxyacetophenone (2MOAP, CAS # 4079-52-1), anthranilic acid (AA; CAS # 118-92-3), and phenethyl anthranilate (PEA; CAS # 1333-18- 6). Untreated barren dump leach pond water served as the control. Chemicals were obtained from Aldrich Chemical Company, Milwaukee, Wisconsin and PMC Specialties Company, Cincinnati, Ohio. Barren dump leach pond water was obtained from Gold Fields Operating Co., Chimney Creek operation. The pond water was assayed and found to have a pH of 10.6, 150 ppm sodium cyanide and 0.0003 oz/ton gold.

A one choice drinking test was used to evaluate repellency, where birds were presented with richter tubes containing plain water (pre and posttreatment periods) or pond water treated with chemical additive (treatment day). Decrement of consumption was taken as a measure of repellency of the additive relative to an individual's pretreatment consumption.

Starlings were adapted to laboratory conditions and assigned to treatment groups in the same manner as described in Experiment 1. In this experiment there were 12 treatment groups, with 6 birds per group for a total of 72 birds. After assignment to a treatment group, a three-day drinking trial was initiated, i.e. pretreatment, treatment, and posttreatment tests. Details of the trial were similar to those described in Experiment 1. Analyses for treatment effects and whether consumption differed from a theoretical value of zero were the same as described above.

RESULTS

Sodium Cyanide Consumption

Mean distilled deionized water consumption among all birds (N = 36) for the six-hour pretreatment test period was 22.05 ml ± 0.95 (standard error). There were no differences among groups for the pretreatment water consumption ($P = 0.867$). Starlings did reduce consumption when water was treated with sodium cyanide ($F = 20.43$, 5,30 df, $P < 0.001$). Starlings significantly reduced consumption when concentrations were greater than 500 ppm (Tukey B $P < 0.05$, Fig. 2), indicating a threshold tolerance level for sodium cyanide. Consumption for all but the two highest concentrations were statistically different from zero consumption ($F = 46.08$, 6,30 df < 0.001).

Avoidance response of water treated with high concentrations of sodium cyanide was formed within the first two-hour test block (Fig. 3; repeated measures anova, time

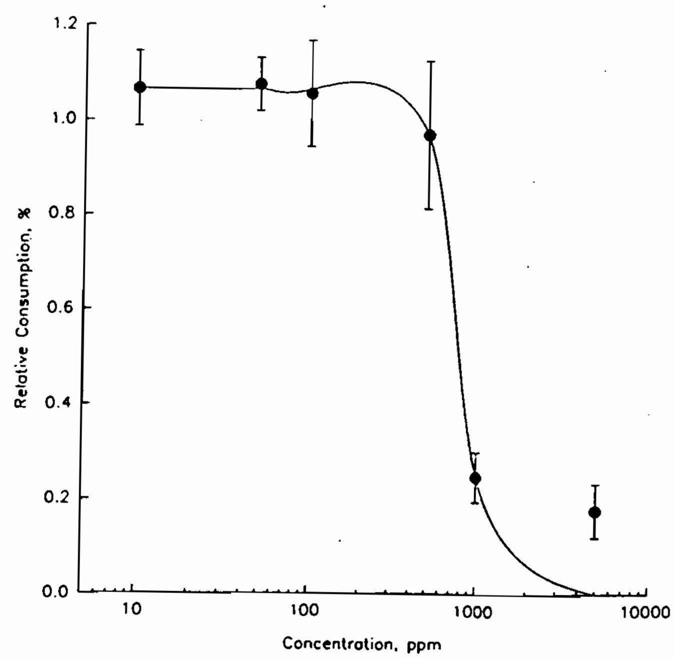

Figure 2. The dose response curve for water containing sodium cyanide. Consumption is depicted as the percent of pretreatment deionized distilled water consumption.

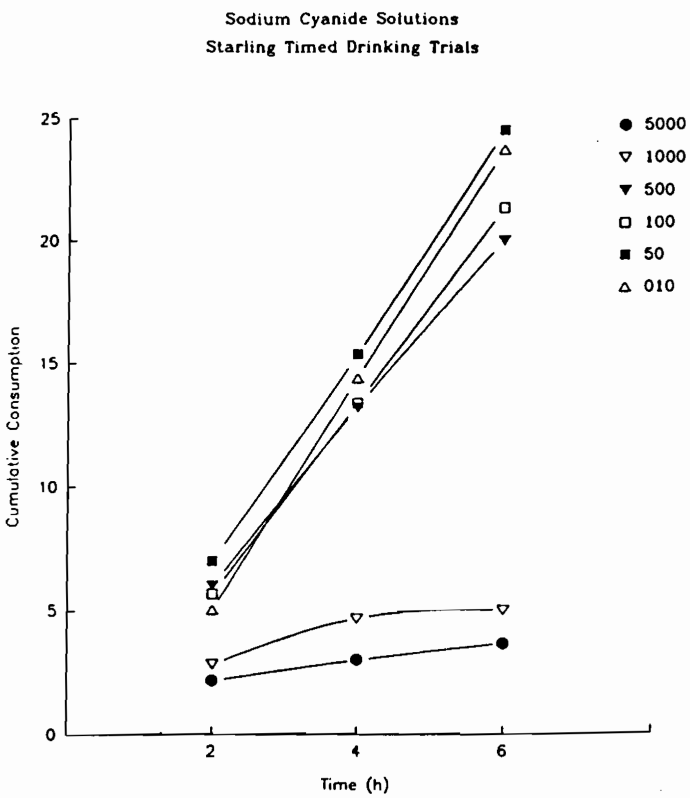

Figure 3. The consumption of sodium cyanide treated water as a function of time course of the experiment. Concentration values listed in the legend are in ppm. Error bars are omitted for clarity.

by concentration effect, F = 4.52, 10,60 df, *P* < 0.001). Profiles of treated water consumption indicated that consumption at concentrations equal to or less than 500 ppm was essentially the same as for deionized distilled water presented during the pretreatment period. For water containing sodium cyanide at 1000 or 5000 ppm, consumption did not substantially increase after the initial exposure. No starlings died as a result of drinking any concentration of sodium cyanide treated water, nor was there an apparent malaise resulting from consumption. In part, high concentrations were not lethal because total consumption was low, resulting in a sublethal dose of toxicant (Table 1).

Consumption of Pond Water Treated with Repellent

The mean tap water consumption during the pretreatment test period among groups for all birds (N = 72) was 24.14±0.82 ml. There were no differences for consumption among the 12 treatment groups (P = 0.838). Addition of a chemical repellent to pond water reduced the relative consumption (F = 7.182, 11, 60 df, P < 0.001). A Tukey B post-hoc test showed that starlings consumed the untreated waste water control and water treated with

Table 1. Consumption of Sodium Cyanide Treated Water by European Starlings

NaCN Concentration (ppm)	Total NaCN Consumed (g)	Hourly Dose (mg/kg)
5000	0.018	38.2
1000	0.005	10.42
500	0.01	20.83
100	0.002	4.45
50	0.001	2.55
10	0.0003	0.53

anthranilic acid, 2-methoxyacetophenone, or phenethyl anthranilate at similar levels. Consumption of these treatments was greater than zero (F = 10.59, 12,60 df, P < 0.001), and was not different from pretreatment consumption of tap water. Starlings curtailed relative consumption of pond water treated with the remaining chemicals (Fig. 4). Water deficits resulting from repellency of treated pond water were compensated during the 16 hours immediately following treatment but before the posttreatment test period (Fig. 4). There were no differences in relative water consumption among treatment groups 24 hours after the treatment period (Fig. 4, P = 0.9), indicating no adverse affects of consuming either repellents and/or pond water.

DISCUSSION

Starlings proved to be remarkably resilient when challenged with sodium cyanide. The average dosage for the higher concentrations tested was well beyond LD_{50} levels reported for rodents (15mg/kg for rats, Merck Index 1983), indicating a physiological ability to cope with the toxicant. Tolerance for sodium cyanide ingestion for other avian species, however, should not be extrapolated from these data. Indeed, other birds are apparently more sensitive to sodium cyanide (R. Clark, personal comm., U.S.F.W.S., Patuxent, MD). Also, the kills reported at mine ponds where cyanide concentration exceed 50 ppm suggest that other species drink more water, thus accumulating a toxic dose, or have lower tolerance. Increased consumption is likely unless birds are otherwise disueded from using toxic impoundments.

Starlings also exhibited a behavioral avoidance response when presented with higher concentrations of sodium cyanide. Apart from any sensory cues that sodium cyanide may possess, starlings may have avoided higher concentration solutions because of the high concentrations of disassociated sodium (Kare and Beily 1948). Many terrestrial birds will not consume water that is hypertonic to their body tissue (Kare 1965).

Despite their apparent resistance to cyanide poisoning, starlings are still a good model for evaluating the effectiveness of repellents. Work in the study laboratory has

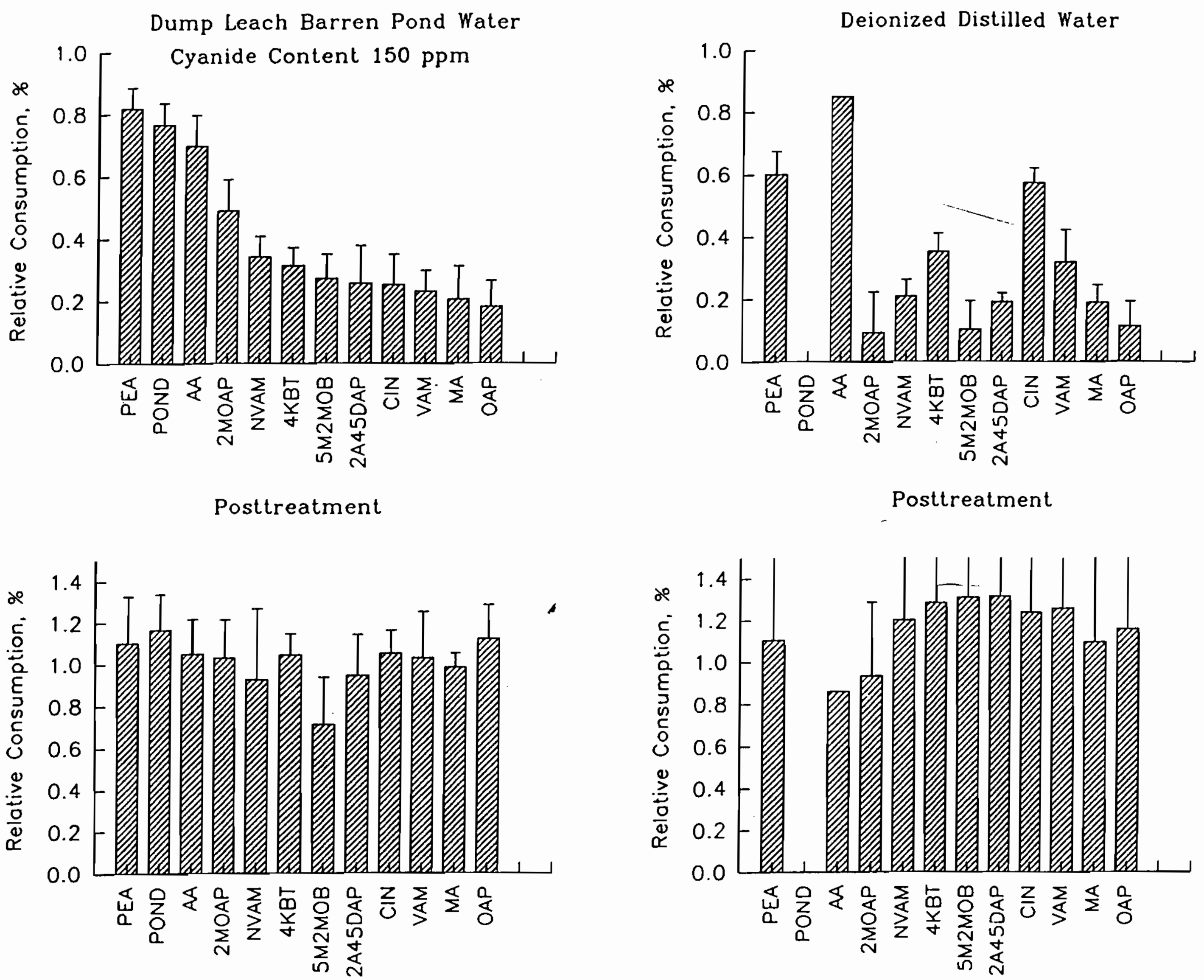

Figure 4. Consumption of water relative to pretreatment consumption as a function of additive. [Top left] Relative consumption for mine pond water containing a 5 percent concentration of chemical additive. Codes for chemicals are found in the text. Pond was the control (no chemical added). [Bottom left] Relative consumption of tap water on the day following treatment with chemical. Consumption returned to normal. [Top right] Relative consumption for deionized distilled water containing a 5 percent concentration of chemical additive. Data were derived from previous studies cited in the text. [Bottom right] Relative consumption of deionized distilled water on the day following treatment with chemical. These data were derived from the same experiments as those in the top right panel. Vertical bars are +1 standard error.

shown that starlings may be slightly less sensitive to repellents than mallards (*Anas platyrhynchos*) and ring-billed gulls (*Larus delawarensis*), thus making estimates of the effectiveness of a repellent based on starlings a conservative estimate (Mason et al. 1989, Clark and Shah 1991, Dolbeer et al. 1991). Slight differences in sensitivity notwithstanding, chemicals that are repellent, are broadly repellent across taxa within Aves (Kare and Pick 1960, Kare 1965, Mason and Otis 1990).

Previous studies showed that most of the chemicals selected for this study were repellent to birds when presented in distilled water (Fig. 4; Clark and Shah 1991, Clark et al. 1991, Shah et al. 1991). If these repellents are to have utility in the field, however, they must retain their repellent properties under hostile chemical conditions, e.g., cyanide containing dump leach pond water.

Anthranilic acid was not an effective repellent in distilled water, nor was it an effective repellent when added to pond water. Phenethyl anthranilate was weakly repellent in distilled water, yielding a 40 percent reduction in consumption, but repellent activity was essentially destroyed when it was added to pond water. Hydrolysis of the ester under alkaline conditions may explain this loss of activity. This was confirmed when UV spectra data indicated a 95 percent reduction of phenethyl anthranilate concentration in pond water relative to that found in deionized distilled water.

Cinnamamide was only weakly repellent in distilled water, again, yielding a 40 percent reduction in consumption relative to pretreatment levels. When added to pond water, however, repellency was increased to yield a 75 percent reduction in relative water consumption. Chemical analysis of the test samples showed that cinnamamide was highly insoluble in distilled water and that solubility increased under the more alkaline conditions present in pond water. Thus, the change in effectiveness is really a consequence of increased concentration of the repellent in the pond water presentation.

The remainder of the repellents did not show significant changes in effectiveness between the two solutions, and chemical analysis indicated that the chemicals remained largely intact after 12 hours. Unexpectedly, methyl anthranilate retained its repellency in pond water. It was anticipated that hydrolysis of the ester would occur yielding anthranilic acid. Analysis of the pond water samples treated with methyl anthranilate, however, indicated that methyl anthranilate was still present in the sample in its original concentration. These results are encouraging because persistence is a key ingredient in maintaining economic viability of potential repellents. Further study is required to examine the persistence of compounds over longer periods, and to evaluate repellency to birds after these periods.

Although only data on the applicability of chemical repellents in deterring consumption of mine tailing pond water containing cyanide are presented, these repellents may have other uses. Field tests are under way to treat free standing water on airport runways in an effort to decrease the risk of air strikes between birds and aircraft. Many airports report numerous air strikes with birds (Blokpoel 1976). In 1989 the economic losses to the U.S. military operations were on the order of $80 million. Civilian losses were reported to be a minimum of $100 million (USDA-FAA Liaison Office, Atlantic City). Birds are often attracted to airports after rains because of the freestanding water, which accumulates on tarmacks and runways. As is the case in mining operations, traditional hazing techniques are ineffective in that the birds are only moved from one location to another near the airport or soon become habituated to the hazing. The goal is to dissuade the birds from using the airport at all.

Trials for the treatment of water at fish hatcheries are also being conducted in an attempt to reduce bird predation on fingerlings. The pond-side value of aquaculture for the U.S. was approximately $700 million with a final sales value of $3.77 billion for 1988. Catfish are an important component of the aquaculture industry. Pond-side value of the catfish industry was $323 million, or approximately 46 percent of the industry total. At the present time demand for hatchery raised catfish exceeds the industry's ability to produce the product. Thus, any loss cuts into potential profits. Losses for catfish, of which a major portion are attributed to depredation by birds, were 10 percent nationally, resulting in a total of loss of $32 million in pond-side value of catfish.

Steps to decrease bird depredation on fish can be costly. The most effective method of keeping birds out of the hatchery ponds is to excluded them physically with nets. Conservative estimates for netting run about $10,000–15,000/acre. Costs rise exponentially for ponds over 40 acres because of engineering constraints in keeping nets aloft. Hazing may work if ponds are aggressively protected and hazing is reinforced with lethal control. The downside to lethal control is that it does not fare well in public opinion, a factor to consider if the market is to expand and avoid consumer boycotts. (Note how dolphins became a rallying point against the tuna industry.) Lethal control is also at odds with regulatory statutes for the protection of migratory birds. Even if lethal control were allowed, some ponds are so large that birds can stay out of range. For acquaculture, the logistical problems of delivery and persistence are compounded with the additional problem of providing a repellent that does not confer an off flavor to fish and is not harmful to fish, and secondarily to humans.

Although laboratory tests are not necessarily an indication that the technique will work in the field, the progress that has been made in this area is encouraging. Not so long ago the consensus was that birds did not have sensory systems sensitive enough to warrant attempts to develop repellents. There is now a better understanding of avian sensory systems and how their properties might be exploited in the development of chemical repellents (Mason et al. 1989, Clark et al. 1991). The success of chemical repellents in experimental agricultural applications has shown how laboratory findings can be applied (Mason et al. 1985, 1991a, Glahn et al. 1989). Furthermore, the emphasis on nonlethal means to control wildlife populations when conflicts arise places increased importance on efforts to discover and implement practical solutions. Thus, a first step in this process is to develop the tools (repellents) needed for nonlethal control. With the development of a molecular model for predicting bird repellents from chemical structure, this goal is closer to attainment.

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